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# Pyroelectric X-Ray Detectors and X-Ray Pyrometers*

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Abstract

Pyroelectric detectors are very promising x-ray detectors for intense pulsed x-ray/γ-ray measurements and can be used as x-ray pyrometers. They are fast, passive, and inherently flat in spectral response for low energy x-rays. We report our tests of $LiTaO_3$, $Sr_{.5}Ba_{.5}Nb_2O_6$ and $LiNbO_3$ detectors at Nova Laser with 1 ns low energy x-rays and at Zapp Z-pinch machine with 100 ns x-rays. The temporal and spectral responses are discussed.

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## Introduction

Pyroelectric detectors are very sensitive thermometers that can detect a temperature change of 1 μdeg,[1] and are widely used in infrared measurements. Although they are seldom used in x-ray applications, pyroelectric detectors appear to be very promising for intense pulsed x-ray measurements and can be used as fast x-ray pyrometers.

## I. Interesting Characteristics of Pyroelectric Detectors

The most interesting characteristics of the pyroelectric detector for x-ray application is perhaps its flat spectral response to x-rays. The spectral response is expected to be inherently flat inasmuch as the x-rays are totally absorbed in the pyroelectric crystal and are converted into heat. Since the pyroelectric detector can be made fast, being ultimately limited by the phonon vibration rate of the crystal lattice that is of the order of 1 picosecond,[2] it can be used as a fast calorimeter. A fast calorimeter is valuable because a single detector can measure the total output power from a pulsed x-ray source.

Another interesting characteristic of the pyroelectric detector is that it is a passive device; that is, no bias voltage is required. This simplifies experimental setup and can be important in some applications.

## II. Impulse Response

The pyroelectric phenomenum is based on the change of the spontaneous polarization of a ferroelectric crystal due to the change of temperature upon absorption of heat or radiation. Thus, the pyroelectric displacement current is proportional to the rate of change of the crystal temperature. This often leads to the confusion whether the response of the detector is the derivative of the input pulse or not. To clarify the situation, let's consider a square input pulse. For an adiabatic detector, of which the thermal relaxation time is much longer than the duration of the input pulse, the rate of change of the crystal temperature is a constant, namely the crystal temperature keeps rising at the same rate during the input pulse. Thus, the pyroelectric current is a constant resulting in a square output voltage (not the derivative) on the load. Naturally, if either the thermal relaxation time is not much longer or the RC time constant of the associated electric circuit is not much shorter than the input pulse, the output pulse will be affected accordingly.

We have been testing $LiTaO_3$, $Sr_{.5}Ba_{.5}Nb_2O_6$ (SBN) and $LiNbO_3$ detectors at the Nova Laser Facility and at the Zapp Z-pinch machine of our Laboratory. $LiNbO_3$ has a high Curie temperature (1210°C), SBN has a large pyroelectric coefficient ($6.5 \times 10^{-8}$ Coul $cm^{-2}$ $°K^{-1}$), while $LiTaO_3$ is commonly used. The response of a $LiTaO_3$ detector to low energy x-rays from a Nova target is shown in Fig. 1. A 0.35 µm, 1.6 KJ and 1 ns Nova beam was focused onto a gold target at $2 \times 10^{15}$ $w/cm^2$, and the x-rays were filtered with a 0.39 µm Al filter. The detector is 1 cm x 1 cm x 50 µm and placed at 440 cm from the target. Clearly, pyroelectric detectors are sensitive enough for this type of application. Fig. 2 shows the response of a $LiTaO_3$ detector to a 100 ns x-ray pulse from the Zapp Z-pinch machine. The detector is 1 mm in diameter and was placed behind a 0.39 µm Al filter at 40 cm from the plasma pinch. The pulse shape is close to that of an x-ray diode, indicating a good response for such a relatively long pulse.

## III. Spectral Responsee

As mentioned earlier, the spectral response of the pyroelectric detectors ought to be inherently flat, so long as the x-rays are totally absorbed and converted into heat. Even though there is no evidence against this assertion, it is important to prove it experimentally; and in particular, to calibrate the sensitivity of the detector.

As a first step toward this goal, we have correlated the $LiTaO_3$ signals to the absolutely-calibrated broadband low energy x-ray spectrometer "Dante," a 15-channel, filtered x-ray diode system. The procedure is shown in Fig. 3(a) through Fig. 3(d). Fig. 3(a) shows the measured x-ray spectrum from a Nova target, Fig. 3(b) is the transmission of a 0.39 μm Al filter. Multiplying Fig. 3(a) and Fig. 3(b) gives the spectrum incident on the $LiTaO_3$ detector. Integrating Fig. 3(c) gives Fig. 3(d) which should correlate linearly with the $LiTaO_3$ signal. The result of the correlation from five Nova target shots is plotted in Fig. 4. It shows that the spectral response of the x-ray pyrometer is indeed flat above ~400 eV, where 90% of the Dante signal is contained. As a next step, we are planning to calibrate the detectors corresponding to the filter-mirror channels of the Dante system.

References

1. See for example E. H. Putley, "The Pyroelectric Detector," Semiconductors and Semimetals, Vol. 5, R. K. Willardson and A. C. Beer, editors (Academic Press, N.Y., 1970) 259-285.

2. C. B. Roundy, "Performance and Uses of High Speed Pyroelectric Detectors," SPIE, Vol. 62, Infrared Technology, 191-198 (1975).

Figure Captions

1. A typical impulse response of $LiTaO_3$ to low energy x-rays from the Nova target.
2. A typical x-ray pulse from a Z-pinch plasma observed with a $LiTaO_3$ detector.
3. The procedure of correlating the measured x-ray spectrum to the pyroelectric signal. (See text for details)
4. Correlating the measured x-ray spectra to the pyroelectric signals.

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# Impulse response of $LiTaO_3$ to low energy x-rays from Nova target

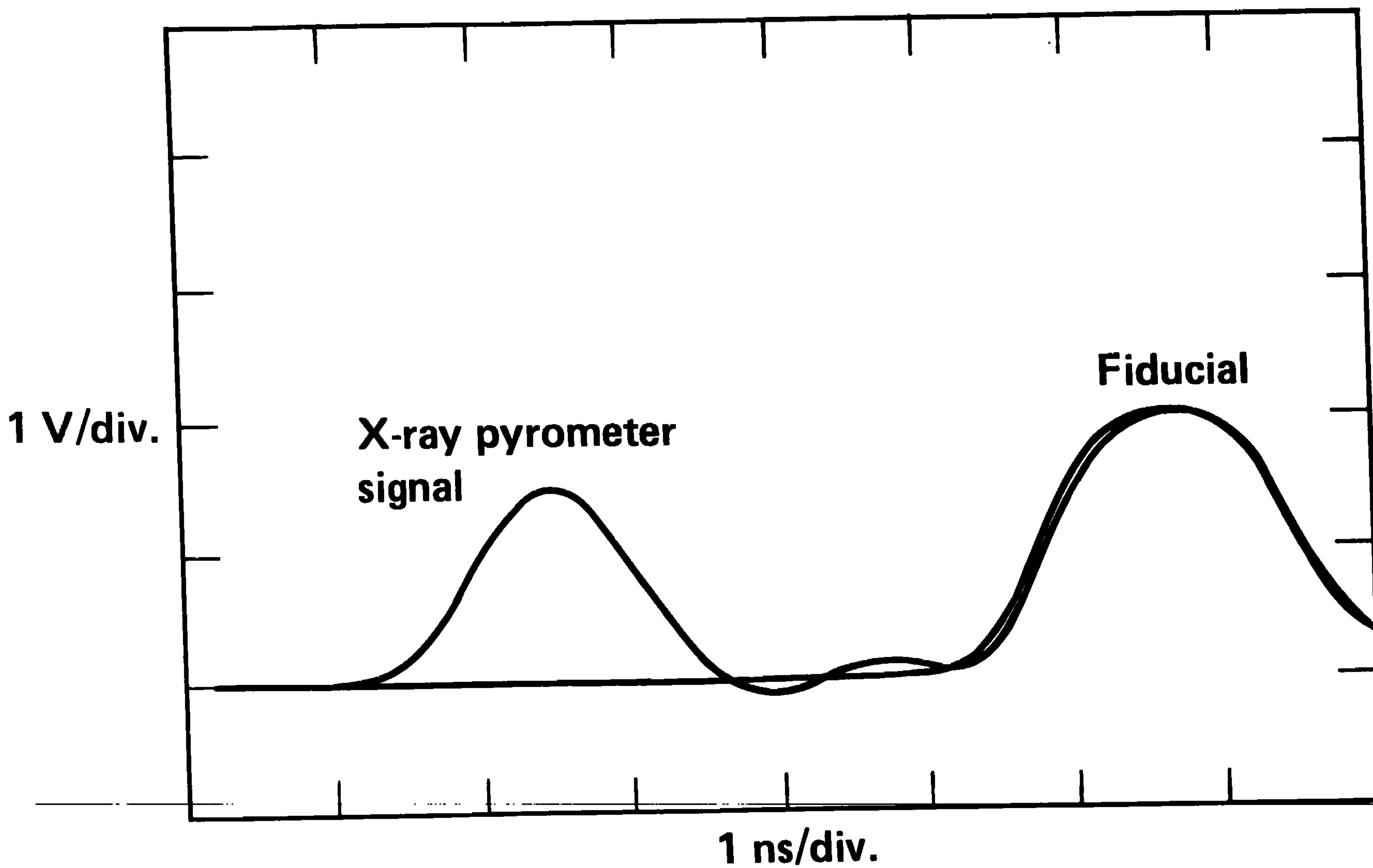


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Fig. 1

# Impulse response of $LiTaO_3$ to low energy x-rays from a Z-pinch machine

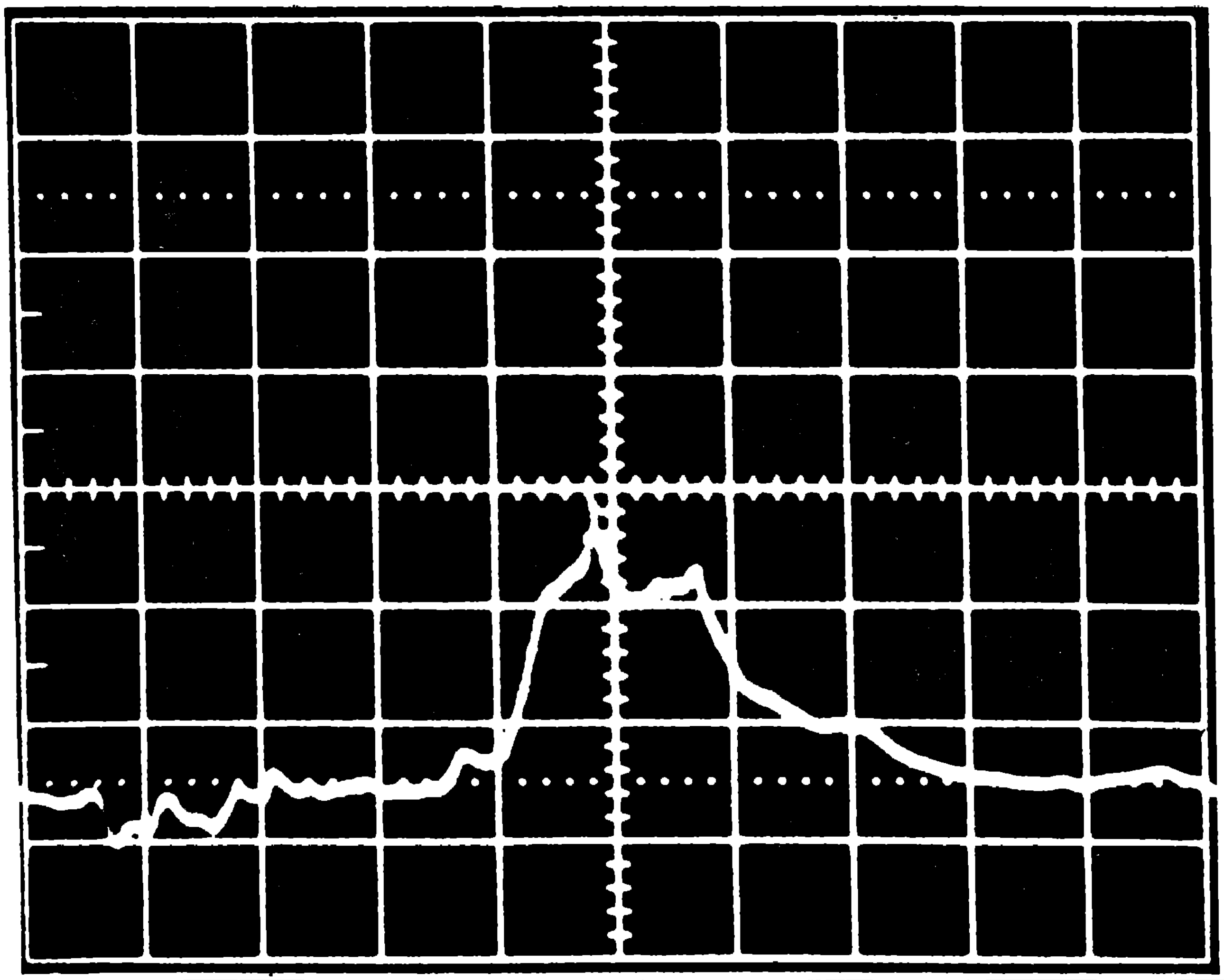


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Fig. 2

# Procedure for integrating transmitted x-ray spectrum

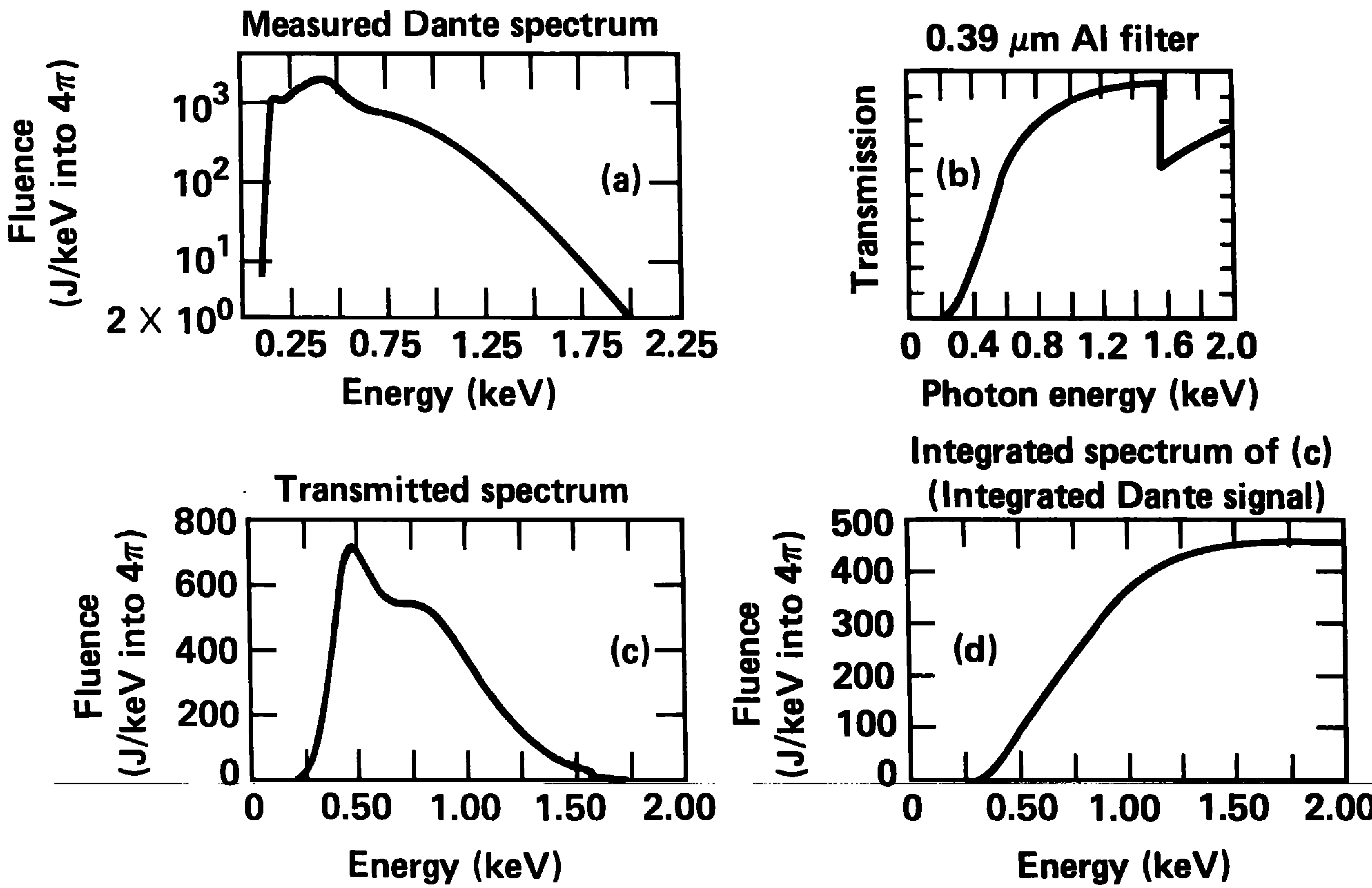


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Fig. 3

## Correlating pyrometer signals and Dante signals

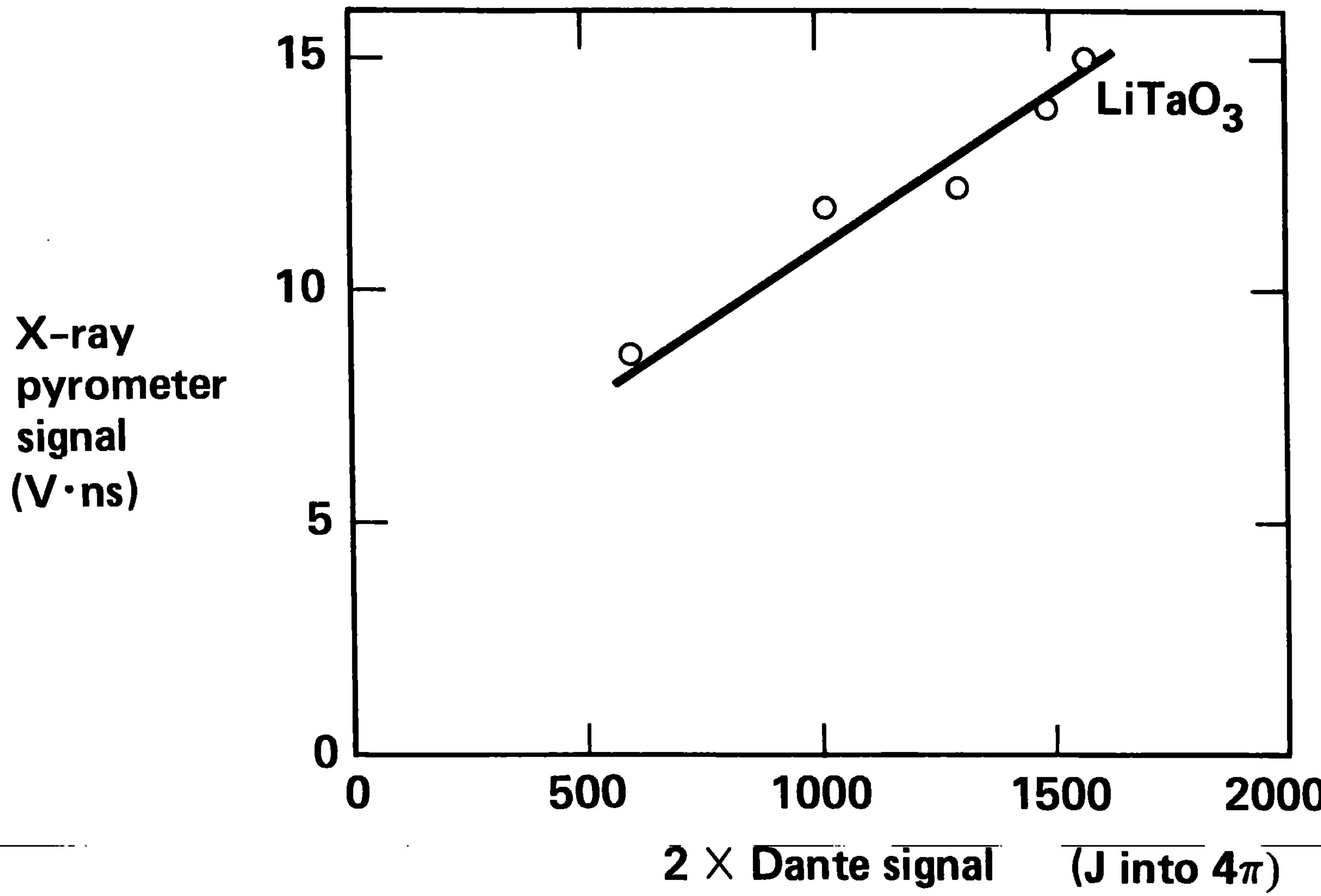


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Fig. 4